

## **THE CLAIMS**

### **What is claimed is:**

1. A ferroelectric PZT material, having a dimensionally scalable, pulse length scalable and/or E-field scalable character.
2. A ferroelectric PZT material having a dimensionally scalable character.
3. A ferroelectric PZT material having a pulse length scalable character.
4. A ferroelectric PZT material having an E-field scalable character.
5. A ferroelectric PZT material having a dimensionally scalable character and a pulse length scalable character.
6. A ferroelectric PZT material having a dimensionally scalable character and an E-field scalable character.
7. A ferroelectric PZT material having a pulse length scalable character and an E-field scalable character.
8. A ferroelectric PZT material, having a dimensionally scalable, pulse length scalable and E-field scalable character.

9. The PZT material of claim 1, having a thickness of from about 20 to about 150 nanometers.
10. The PZT material of claim 1, having a ferroelectric operating voltage below 2 Volts.
11. A ferroelectric PZT material, having at least one of Type 1 properties.
12. The PZT material of claim 11, wherein at least one of said Type 1 properties includes a ferroelectric polarization  $P_{sw}$  greater than 20  $\mu\text{C}$  per square centimeter.
13. The PZT material of claim 11, wherein at least one of said Type 1 properties includes a leakage current density  $J$  less than  $10^{-5}$  amperes per square centimeter at a ferroelectric operating voltage of the material.
14. The PZT material of claim 11, wherein at least one of said Type 1 properties includes a dielectric relaxation defined by  $J^n \log(\text{time})$  wherein  $n$  is greater than 0.5.
15. The PZT material of claim 11, wherein at least one of said Type 1 properties includes a cycling fatigue defined by  $P_{sw}$  being less than 10% lower than its original value after  $10^{10}$  polarization switching cycles.
16. The PZT material of claim 11, having at least two of Type 1 properties.
17. The PZT material of claim 11, having at least three of Type 1 properties.
18. The PZT material of claim 11, having all of said Type 1 properties.

19. A ferroelectric PZT material having at least one of Type 2 properties.
20. The PZT material of claim 19, wherein at least one of said Type 2 properties includes ferroelectric polarization,  $P_{sw}$ .
21. The PZT material of claim 19, wherein at least one of said Type 2 properties includes coercive E-field,  $E_c$ .
22. The PZT material of claim 19, wherein at least one of said Type 2 properties includes leakage current density,  $J$ .
23. The PZT material of claim 19, wherein at least one of said Type 2 properties includes retention.
24. The PZT material of claim 19, wherein at least one of said Type 2 properties includes cycling fatigue of ferroelectric polarization.
25. The PZT material of claim 19, having at least two of Type 2 properties.
26. The PZT material of claim 19, having at least three of Type 2 properties.
27. The PZT material of claim 19, having at least four of Type 2 properties.
28. The PZT material of claim 19, having all of said Type 2 properties.

29. A ferroelectric PZT material having at least one of Type 1 properties and at least one of Type 2 properties.
30. A capacitor comprising a ferroelectric PZT material according to any one of claims 1 to 29.
31. The capacitor of claim 30, having a capacitor area of from about  $10^4$  to about  $10^{-2} \mu\text{m}^2$ .
32. The capacitor of claim 30, wherein the PZT material is between a bottom electrode formed of a material comprising iridium and/or platinum, and a top electrode formed of a material comprising iridium and/or iridium oxide.
33. The capacitor of claim 30, constituting a stack capacitor.
34. A microelectronic device structure, comprising: a pulse length scalable ferroelectric PZT material; and a power supply and associated circuitry arranged for excitation of the PZT material, wherein the excitation is characterized by an excitation (voltage) pulse length in the range of from 5 nanoseconds to 200 nanoseconds.
35. An FeRAM device, including a capacitor comprising a ferroelectric PZT material according to any one of claims 1 to 29.
36. The FeRAM device of claim 35, having a capacitor area of from about  $10^4$  to about  $10^{-2} \mu\text{m}^2$ .
37. The FeRAM device of claim 35, wherein the PZT material has a ferroelectric operating voltage below 2 Volts.

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38. ~~A method of fabricating a ferroelectric PZT film on a substrate, comprising forming the film by liquid delivery MOCVD on the substrate under MOCVD conditions producing a ferroelectric PZT material according to any one of claims 1 to 29.~~

39. The method of claim 38, wherein the MOCVD conditions include use of a lead source reagent selected from the group consisting of  $\text{Pb}(\text{thd})_2$  and  $\text{Pb}(\text{thd})_2\text{pmdeta}$ .
40. The method of claim 38, wherein the MOCVD conditions include use of a zirconium source reagent selected from the group consisting of  $\text{Zr}(\text{thd})_4$  and  $\text{Zr}(\text{O-i-Pr})_2(\text{thd})_2$ .
41. The method of claim 38, wherein the MOCVD conditions include use of  $\text{Ti}(\text{O-i-Pr})_2(\text{thd})_2$  as a titanium source reagent.
42. The method of claim 38, wherein the MOCVD conditions include use of  $\text{Pb}(\text{thd})_2$ ,  $\text{Ti}(\text{O-i-Pr})_2(\text{thd})_2$  and  $\text{Zr}(\text{thd})_4$  as respective lead, titanium and zirconium source reagents.
43. The method of claim 38, wherein the MOCVD conditions include use of  $\text{Pb}(\text{thd})_2\text{pmdeta}$ ,  $\text{Ti}(\text{O-i-Pr})_2(\text{thd})_2$  and  $\text{Zr}(\text{thd})_4$  as respective lead, titanium and zirconium source reagents.
44. The method of claim 38, wherein the MOCVD conditions include use of  $\text{Pb}(\text{thd})_2\text{pmdeta}$ ,  $\text{Ti}(\text{O-i-Pr})_2(\text{thd})_2$  and  $\text{Zr}(\text{O-i-Pr})_2(\text{thd})_2$  as respective lead, titanium and zirconium source reagents.
45. The method of claim 38, wherein the source reagents are provided for liquid delivery MOCVD in a solvent medium comprising one or more solvent species selected from the group consisting of:

tetrahydrofuran, glyme solvents, alcohols, hydrocarbon solvents, hydroaryl solvents, amines, polyamines, and mixtures of two or more of the foregoing.

46. The method of claim 38, wherein the source reagents are provided for liquid delivery MOCVD in a solvent medium comprising tetrahydrofuran: isopropanol: tetraglyme in an 8:2:1 volume ratio.
47. The method of claim 38, wherein the source reagents are provided for liquid delivery MOCVD in a solvent medium comprising octane: decane: polyamine in a 5:4:1 volume ratio.
48. The method of claim 38, wherein the source reagents are provided for liquid delivery MOCVD in a solvent medium comprising octane: polyamine in a 9:1 volume ratio.
49. The method of claim 38, wherein the source reagents are provided for liquid delivery MOCVD in a solvent medium comprising tetrahydrofuran.
50. The method of claim 38, wherein the substrate comprises a noble metal.
51. The method of claim 38, wherein the substrate comprises a noble metal selected from the group consisting of iridium, platinum, and combinations thereof.
52. The method of claim 38, wherein the substrate comprises a TiAlN barrier layer overlaid by an iridium layer.
53. The method of claim 38, wherein the liquid delivery MOCVD includes vaporization of a source reagent solution to form precursor vapor therefrom and flowing the precursor vapor to a CVD

chamber in a carrier gas.

54. The method of claim 53, wherein the carrier gas is selected from the group consisting of argon, helium and mixtures thereof.

55. The method according to claim 38, further comprising flowing to the CVD chamber an oxidant medium including at least one species selected from the group consisting of  $O_2$ ,  $O_3$ ,  $N_2O$ , and  $O_2/N_2O$ .

56. A method of fabricating a ferroelectric PZT film on a substrate, comprising forming the film by liquid delivery MOCVD on the substrate under MOCVD conditions including nucleation conditions producing a ferroelectric PZT material according to any one of claims 1 to 29.

57. A method of fabricating a ferroelectric PZT film on a substrate, comprising forming the film by liquid delivery MOCVD on the substrate under MOCVD conditions including temperature, pressure and liquid precursor solution A/B ratio determined by plateau effect determination from a correlative empirical matrix of plots of each of ferroelectric polarization, leakage current density and atomic percent lead in PZT films, as a function of each of temperature, pressure and liquid precursor solution A/B ratio, wherein A/B ratio is the ratio of Pb to (Zr + Ti).

58. A method of fabricating a ferroelectric PZT film on a substrate, comprising forming the film by liquid delivery MOCVD on the substrate under MOCVD conditions including temperature, pressure and liquid precursor solution A/B ratio determined by plateau effect determination from a correlative empirical matrix of plots of each of ferroelectric polarization, leakage current density and atomic percent lead in PZT films, as a function of each of temperature, pressure and

liquid precursor solution A/B ratio, wherein A/B ratio is the ratio of Pb to (Zr + Ti), and wherein said ferroelectric PZT film comprises a ferroelectric PZT material according to any one of claims 1 to 29.

59. A method of fabricating a ferroelectric PZT film on a substrate, comprising forming the film by liquid delivery MOCVD on the substrate under MOCVD conditions including Correlative Materials or Processing Requirements, to yield a ferroelectric PZT film having PZT Properties, wherein said Correlative Materials or Processing Requirements and PZT Properties comprise:

| PZT Properties  | Correlative Materials or Processing Requirements  |
|---|---|
| <b>Basic properties:</b>  |   |
| <b>Ferroelectric polarization</b><br>$P_{sw} > 20 \mu\text{C}/\text{cm}^2$  | Film Pb concentration > threshold level;<br>operation on A/B plateau above the knee region,<br>and with temperature, pressure and gas phase<br>A/B concentration ratio defined by plateau effect<br>determination   |
| <b>Leakage current density</b><br>$J < 10^{-5} \text{ A}/\text{cm}^2$ at operating voltage  | Film Pb concentration within a range (between<br>the minimum and maximum) on the A/B plateau,<br>and with temperature, pressure and gas phase<br>A/B concentration ratio defined by plateau effect<br>determination |
| <b>Dielectric relaxation</b><br>For characteristic $J^n \propto \log(\text{time})$ , $n > 0.5$<br>and $J < 1\%$ ferroelectric switching current from<br>0-100 ns. | Zr/Ti ratio < 45/55<br>Deposition P > 1.8 torr  |
| <b>Retention</b><br>Maintenance of ferroelectric properties<br>(ferroelectric domains)  | Operation within ranges of temperature, pressure<br>and gas phase A/B concentration ratio defined by<br>plateau effect determination  |



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| <b>Avoidance of cycling fatigue</b><br>$P_{sw} < 10\%$ decrease after $10^{10}$ cycles | Use of Ir-based electrodes  |
| <b>E-field scalability</b>   | Operation within ranges of temperature, pressure and gas phase A/B concentration ratio defined by plateau effect determination  |
| <b>Surface smoothness</b>  | Nucleation-growth conditions during film formation within ranges of temperature, pressure and gas phase A/B concentration ratio defined by plateau effect determination |
| <b>Grain size</b>  | Nucleation-growth conditions during film formation within ranges of temperature, pressure and gas phase A/B concentration ratio defined by plateau effect determination |

60. A method of fabricating a FeRAM device, comprising forming a capacitor on a substrate including a ferroelectric PZT material according to any one of claims 1 to 29, wherein the ferroelectric PZT material is deposited by liquid delivery MOCVD under MOCVD conditions yielding said ferroelectric PZT material.
61. The method of claim 60, wherein the PZT material has a ferroelectric operating voltage below 2 Volts.
62. The method of claim 60, wherein the PZT film defines a capacitor area of from about  $10^4$  to about  $10^{-2} \mu\text{m}^2$ .
63. The method of claim 60, wherein the MOCVD conditions are determined by plateau effect determination.

64. The method of claim 60, wherein the MOCVD conditions comprise Correlative Materials or Processing Requirements, to yield a ferroelectric PZT film having PZT Properties, wherein said Correlative Materials or Processing Requirements and PZT Properties comprise:

| PZT Properties  | Correlative Materials or Processing Requirements  |
|---|---|
| <b>Basic properties:</b>  |   |
| <b>Ferroelectric polarization</b><br>$P_{sw} > 20 \mu\text{C}/\text{cm}^2$  | Film Pb concentration > threshold level;<br>operation on A/B plateau above the knee region,<br>and with temperature, pressure and gas phase<br>A/B concentration ratio defined by plateau effect<br>determination   |
| <b>Leakage current density</b><br>$J < 10^{-5} \text{ A}/\text{cm}^2$ at operating voltage  | Film Pb concentration within a range (between<br>the minimum and maximum) on the A/B plateau,<br>and with temperature, pressure and gas phase<br>A/B concentration ratio defined by plateau effect<br>determination |
| <b>Dielectric relaxation</b><br>For characteristic $J^n \propto \log(\text{time})$ , $n > 0.5$<br>and $J < 1\%$ ferroelectric switching current from<br>0-100 ns. | Zr/Ti ratio < 45/55<br>Deposition P > 1.8 torr  |
| <b>Retention</b><br>Maintenance of ferroelectric properties<br>(ferroelectric domains)  | Operation within ranges of temperature, pressure<br>and gas phase A/B concentration ratio defined by<br>plateau effect determination  |
| <b>Avoidance of cycling fatigue</b><br>$P_{sw} < 10\%$ decrease after $10^{10}$ cycles  | Use of Ir-based electrodes  |
| <b>E-field scalability</b>  | Operation within ranges of temperature, pressure<br>and gas phase A/B concentration ratio defined by<br>plateau effect determination  |
| <b>Surface smoothness</b>   | Nucleation-growth conditions during film<br>formation within ranges of temperature, pressure  |

|                   |   |
|-------------------|---|
|                   | and gas phase A/B concentration ratio defined by plateau effect determination   |
| <b>Grain size</b> | Nucleation-growth conditions during film formation within ranges of temperature, pressure and gas phase A/B concentration ratio defined by plateau effect determination |